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DELINEATION AND IDENTIFICATION OF RIVER BASIN WATERSHED FORMS USING GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING

DELINEASI DAN IDENTIFIKASI BENTUK DAERAH ALIRAN SUNGAI (DAS) MENGGUNAKAN SISTEM INFORMASI GEOGRAFIS DAN PENGINDERAAN JAUH

Fiqih Azzahra*, Iswahyudi, and Rosmaiti

Student of Agrotechnology Study Program, Faculty of Agriculture, Samudra University, Indonesia
* Corresponding Author. E-mail address: fiqihunsam27@gmail.com

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ABSTRACT

Based on data from the Central Statistics Agency (BPS) in 2024, in the last three years there have been 62 floods in East Aceh Regency, Langsa City, and Aceh Tamiang Regency, with details of 29 incidents in East Aceh, 13 incidents in Langsa City, and 20 incidents in Aceh Tamiang. The high frequency of flooding indicates the need for hydrological studies in the Krueng Bayeun, Krueng Langsa, and Krueng Tamiang River Basins (DAS). This study aims to analyze watershed boundaries, topographic characteristics, and the shape and pattern of river flow direction using a Geographic Information System (GIS) based on Digital Elevation Model (DEM) data. The study was conducted using a quantitative descriptive survey method through remote sensing analysis. The results of the Spatial Analyst Hydrology analysis show that the watershed area is depicted in the form of a polygon as the main watershed area. The roundness ratio values of the Krueng Bayeun, Krueng Langsa, and Krueng Tamiang watersheds are 0.23; 0.30; and 0.34, respectively, indicating that the three watersheds are elongated. Water flow is focused toward low-lying areas, potentially increasing water accumulation and the risk of flooding, especially during the rainy season. All three watersheds are dominated by dendritic drainage patterns with moderate river density, indicating sufficient water reserves. The Krueng Bayeun and Krueng Langsa watersheds are dominated by flat to gentle slopes, resulting in slower river flow and longer retention of standing water. Meanwhile, the Krueng Tamiang watershed is dominated by steep to very steep slopes, accelerating flow, increasing erosion, and potentially causing flooding in downstream areas.

ABSTRAK

Berdasarkan data Badan Pusat Statistik (BPS) tahun 2024, dalam tiga tahun terakhir terjadi 62 kejadian banjir di Kabupaten Aceh Timur, Kota Langsa, dan Kabupaten Aceh Tamiang, dengan rincian 29 kejadian di Aceh Timur, 13 kejadian di Kota Langsa, dan 20 kejadian di Aceh Tamiang. Tingginya frekuensi banjir menunjukkan perlunya kajian hidrologi pada Daerah Aliran Sungai (DAS) Krueng Bayeun, Krueng Langsa, dan Krueng Tamiang. Penelitian ini bertujuan menganalisis batas DAS, karakteristik topografi, serta bentuk dan pola arah aliran sungai menggunakan Sistem Informasi Geografis (SIG) berbasis data Digital Elevation Model (DEM). Penelitian dilakukan dengan metode survei deskriptif kuantitatif melalui analisis penginderaan jauh. Hasil analisis Spatial Analyst Hydrology menunjukkan bahwa cakupan wilayah DAS tergambar dalam bentuk poligon sebagai daerah tangkapan air utama. Nilai *roundness ratio* DAS Krueng Bayeun, Krueng Langsa, dan Krueng Tamiang masing-masing sebesar 0,23; 0,30; dan 0,34 yang mengindikasikan bahwa ketiga DAS berbentuk memanjang. Arah aliran air terfokus menuju daerah rendah sehingga berpotensi meningkatkan akumulasi air dan risiko banjir, terutama pada musim hujan. Ketiga DAS didominasi pola aliran dendritik dengan kerapatan sungai kelas sedang yang menunjukkan ketersediaan cadangan air yang cukup. DAS Krueng Bayeun dan Krueng Langsa didominasi lereng datar hingga landai sehingga aliran sungai lebih lambat dan genangan bertahan lebih lama, sedangkan DAS Krueng Tamiang didominasi lereng curam hingga sangat curam yang mempercepat aliran, meningkatkan erosi, dan berpotensi menimbulkan banjir di wilayah hilir.

KATA KUNCI:

Bioaktif, biofortifikasi selenium, daya LED biru, microgreens kubis merah, produksi

1. INTRODUCTION

The development of remote sensing technology and geographic information systems (GIS) has progressed rapidly, enabling the rapid and accurate collection and analysis of spatial data on a large scale. This technology plays an important role in monitoring environmental changes, managing water resources, and mitigating hydrological disasters. The use of digital elevation data (Digital Elevation Model/DEM) in particular provides opportunities to analyze the characteristics of watersheds (DAS) in more detail and in an integrated manner. The advantages of Digital Elevation Model (DEM) data, a product of remote sensing technology, as input data in watershed morphometric analysis include speed, accuracy, up-to-dateness, and affordability. GIS techniques provide methods for manipulating spatial information (Godif & Manjunatha, 2022).

The use of remote sensing data and GIS techniques is highly effective in watershed morphometric analysis, helping to understand watershed development, compare watershed characteristics, manage watersheds, and identify flood risks. DEM data used by several researchers in watershed morphometric analysis include the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a 30-m resolution, the Shuttle Radar Topography Mission (SRTM) with a 30-m resolution, and the Advanced Land Observing Satellite (ALOS) with a 30-m resolution. The higher the resolution of DEM data, the higher the accuracy through increased precision in the delineation process, especially in surface flow networks (Shekar & Mathew, 2024). SRTM DEM are superior to ASTER DEMs because ASTER DEM still contain systematic errors and are significantly affected by weather conditions (Kabite & Gessesse, 2018). SRTM DEM are also more accurate than ASTER DEMs and ALOS PALSAR DEMs (Chowdhury, 2024). Previous studies have extensively used SRTM DEM data for watershed morphometric analysis, including those by Bharath *et al*., 2021; Godif & Manjunatha, 2022; Saha *et al*., 2022; Yawar *et al*., 2023; Kamaraj *et al*., 2024.

Morphometry can predict watershed hydrological conditions and is appropriate for analyzing area distribution patterns and providing a complex surface figure of watershed morphological heterogeneity (Anand *et al*., 2020). Ecosystem change factors and watershed physical conditions can affect changes in hydrology, while watershed hydrology is not only governed by the morphological conditions of basins and slopes but also affected by the geological properties of bedrock, soil thickness, land use, and lan cover (Letsinger *et al*., 2020). Comparison andevaluation of morphometric data can be analyzed through conventional methods, manuals, geospatial techniques, and mathematical analysis (Farhan *et al*., 2015). The development of geospatial analytical techniques (GIS and RS) and other tools can be usedto measure and calculate morphometric parameters onbasic aspects that are integrated with mathematicalequations to calculate linear, area, and relief parameters (Prasannakumar *et al*., 2013).

Watershed management is an important aspect of water resource planning because it is directly related to the balance of the hydrological cycle (Kemenhut, 2013). However, efforts to mitigate and prevent hydrogeological disasters in Indonesia often do not take into account the morphological and topographical characteristics of watersheds as a whole. The condition is reflected in the increasing number of floods during the rainy season and droughts during the dry season in various regions, which indicates a decline in the ability of watersheds to regulate water flow naturally.

The eastern coastal region of Aceh Province, particulary East Aceh Regency, Langsa City, and Aceh Tamiang Regency, is an area prone to flooding. Based on BPS data (2024) in the last three years there have been 62 floods in East Aceh Regency, Langsa City and Aceh Tamiang Regency with details in East Aceh Regency there were 29 floods, in Langsa City 13 times and Aceh Tamiang Regency 26 times. Although several provious studies have examined the morphometric characteristics of watersheds in various regions of Indonesia, studies comoaring several watersheds of different scales within a single physographic region, particularly based on national resolution DEM, are still relatively limited.

Watershed management requires information on watershed characteristics, both static and dynamic characteristics. One of the static characteristics of a watershed is watershed morphometry. (Ditjen BPDAS-PS, 2013). Watershed morphometric analysis has been widely used to evaluate hydrological characteristics and potential flash flood hazards because it represents the geomorphological conditions that control flow response within a watershed. Linear, relief, and areal morphometric parameters can describe the characteristics of the drainage network, elevation differences, watershed shape, and potential flow concentrations, which influence runoff generation and peak discharge (Chaithong *et al*., 2022). Recent studies have also shown that watershed geomorphological parameters can be used to analyze flash flood vulnerability and understand changes in extreme flow due to the influence of regional physical characteristics, land use, and climatic conditions (Belay *et al*., 2025; Han *et al*., 2025).

Based on these conditions, this study aims to analyze the watershed boundaries, topographic characteristics, and river flow patterns in the Krueng Bayeun, Krueng Langsa, and Krueng Tamiang watersheds using a geographic information system based on DEMNAS data. The uniqueness of this study lies in its comparative approach to three watersheds of different sizes within the same physiographic region, as well as the integration of morphometric parameters and slope classes to explain variation in hydrological response and flood potential. This approach is expected to provide a more comprehensive understanding than previous studies, which were generally partial and descriptive in nature.

2. MATERIALS AND METHOD

2.1 Study Area and Time of Research

The research location is on the east coast of Aceh Province, namely Krueng Bayeun, Krueng Langsa, and Krueng Tamiang. The research period is 4 months, starting in June and ending in September 2024. Data processing was carried out at the Remote Sensing and Cartography Laboratory of the Soil Science Study Program, Faculty of Agriculture, Syiah Kuala University, Banda Aceh. The research location can be seen in Figure 1.

2.2 Tools and Materials

The tools used in this study include: a set of laptops that have been installed with ArchMap 10.8 software, Global Mapper, GPS (Global Positioning System), a digital camera for documenting field conditions and stationery. The materials used in this study include a map of the administrative boundaries of the research area with a scale of 1:50,000 and Digital Elevation Model (DEM) data.

2.3 Method

This study uses a survey method with descriptive analysis techniques. The purpose of descriptive research is to explain a symptom, event and condition that is currently occurring in the field by recording and analyzing various data that have been obtained in the field (Soendari, 2012). Survey activities were carried out to see the direct conditions of the Krueng Bayeun, Krueng Langsa, and Krueng Tamiang River Basin Watershed outlets. Spatial data analysis was carried out using the Spatial Analyst Hydrology Method to determine the shape of the River Basin Watershed and map the boundaries of the Watershed (water catchment area, main river flow and tributaries).

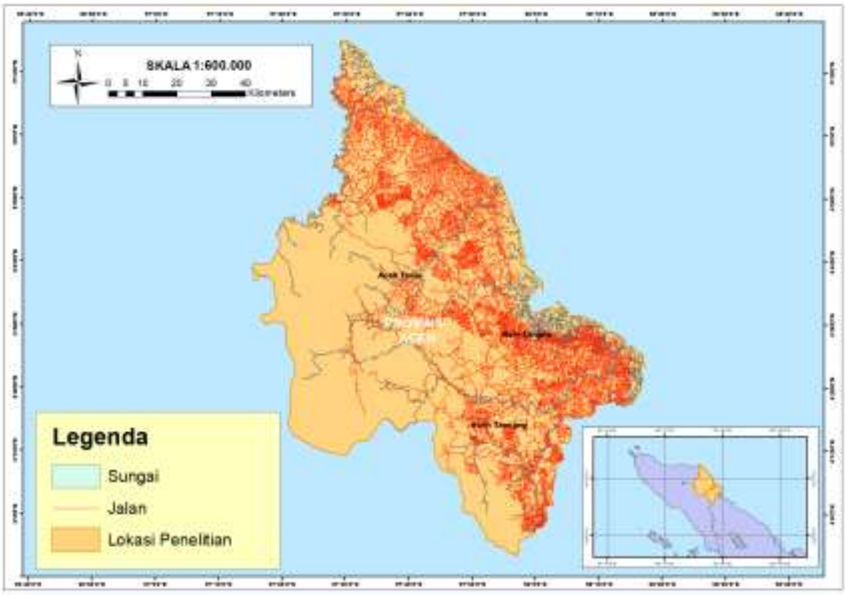

Figure 1. Research Location Map

2.4 Pre Data Analysis

The data analysis process is carried out by processing DEM data using Global Mapper software to combine several DEMs. The method used in this study is the Spatial Analyst Hydrology method with the tools available on ArcGIS Desktop 10.8, namely: (1) The delineation process of Krueng Bayeun, Krueng Langsa, and Krueng Tamiang uses DEMNAS data. DEMNAS data needs to be transformed into a Universal Transverse Mercator (UTM) projection system. The transformation used is UTM 47N; (2) DEMNAS data is then corrected with the fill data tool to fill in the sink information contained in the map. A sink is an area that has its own water flow, this water does not flow out. In the real world, sinks can be lakes, ponds or holes due to poor data processing; (3) After filling, the next stage is flow direction which is a stage to determine the direction of flow from the surface represented by the DEMNAS data cells. Enter flow direction data in the form of fill results, while the flow direction results are in the form of flow direction data at each surface height; (4) The flow accumulation stage is a further stage after the flow direction is known with the cell value formed from the flow direction data. The highest cell value receives flow from each cell upstream. The results of flow accumulation, white represents cells with large values. This value can be interpreted as the point where water collects and flows; (5) Catchment outlet ("pour") points or determining the outlet point, there is one stage that must be carried out, namely determining the outlet point of the water flow which will be the reference in the watershed area delineation process. Creating an outlet point or snap pour point can be done by creating a shapefile point that becomes the outlet point; (6) Delineating the watershed area, in this process it can be done by entering the flow direction raster and snap pour point. If all the data information is correct, then the watershed area can be formed according to the assumption of the outlet point that has been determined. The results of the watershed area are in the form of Watershed data (Purboyo, 2024).

2.5 Data Analysis

DEM data visualization will produce a river network and watershed boundaries, from these results the shape of the river flow can be identified using the watershed roundness ratio and guidelines for physical characteristics of the watershed in accordance with the Republic of Indonesia Government Regulation Number 37 of 2012 concerning Watershed Management. The river flow pattern is the movement of river currents that describe how and where the water flows which eventually empties into the sea.

The depiction of the watershed based on the pour point or outlet (the final discharge point of the flow) aims to determine the watershed boundaries automatically. The digitization of the outlet location is placed right downstream of the river which can be seen directly from the river network that has been obtained from the results of the DEM data visualization. The watershed boundary will be formed after digitizing the outlet location from the sub-watershed using the watershed tools in Spatial Analyst Hydrology. The final result of the watershed process in the form of raster data is then exported to polygons, then the watershed vector data (polygons) will be used in the process of making a watershed shape map.

2.6 Morphometric Characteristic

2.6.1 Watershed Area

Classification of Watershed Areas (DAS) can be determined from the area of the watershed area (DAS), this parameter can be estimated by measuring the area of the DAS area on a topographic map. Determination of DAS boundaries can be determined by contours to determine the direction of surface runoff. Runoff comes from the highest point and moves towards a lower point in a direction perpendicular to the contour line. Classification of DAS based on its area can be classified in Table 1.

Table 1. Classification of watersheds based on their area

Watershed Area (Ha)	Watershed Classification
1.500.000 and above	Very Large Watershed
500.000 - < 1.500.000	Large Watershed
100.000 - < 500.000	Medium Watershed
10.000 - < 100.000	Small Watershed
Less than 10.000	Very Small Watershed

Source: Ministry Forestry, 2013.

Table 2. River Density Classification

Dd	Density Class	Description
0,25	Low	The river channel passes through rocks with hard resistance, so the sediment transport lifted in the river flow is smaller when compared to the river channel that passes through relief with softer resistance, if other conditions that affect it are the same.
0,25-10	Medium	The river channel passes through rocks with softer resistance, so the sediment transport carried by the flow will be greater.
10-25	High	he river channel passes through rocks with soft resistance so the sediment transport carried by the flow will be greater.
> 25	Very High	The river channel passes through impermeable rocks, this condition will indicate that rainwater that causes the flow will be greater when compared to an area with low Dd passing through rocks with high permeability.

Source: Soewarno (1991); Purboyo *et al.*, (2024).

Table 3. Roundness of River Basin Area Watershed

Rc	Description
>0,5	Rounded River Basin Area
<0,5	Elongated River Basin Area

Source: Soewarno (1991); Prabowo (2018).

2.6.2 Order and Level of River Branching

River order is the branching position of the river channel in its sequence to the main river in a watershed, the more river orders there are, the wider the watershed will be and the longer the river channel will be. The river branching level (bifurcation ratio) is an index number determined based on the number of river channels for an order. The river branching level can be calculated using the formula (Soewarno (1991); (Sobatnu *et al*., 2017):

$$\boldsymbol{Rb} = \frac{\boldsymbol{Nu}}{\boldsymbol{Nu+1}} \quad (1)$$

Note: Rb = River branching index. Nu = Number of river channels for order u. Nu+1 = Number of river channels for order u+1.

2.6.3 River Density

Flow density, is an index number that shows the number of tributaries in a watershed. The river density index is obtained from the calculation of the total length of the river divided by the area of the watershed. Equation 2 is the calculation of river density and table 1 is the classification of river density classes (Soewarno (1991); Purboyo *et al*., (2024)).

$$\boldsymbol{Dd} = \frac{\boldsymbol{L}}{\boldsymbol{A}} \quad (2)$$

Note: Dd = River density index (km/km^2). L = Total length of river including tributaries. A = Watershed area (km^2).

2.6.4 River Shape

The shape of the River Basin Watershed has an important meaning in relation to river flow, namely it greatly influences the centralized flow velocity. To determine the shape of the Watershed, it can be determined by determining the Rc value (Roundness Ratio) with the following formula (Soewarno (1991); Prabowo (2018)):

$$Rc = \frac{4\pi \mathrm{A}}{P^2} \quad (3)$$

Note: Rc = Basin circularity/roundness ratio (km/km^2). A = Watershed area (km^2). P = Watershed circumference (km). π = 3.14.

Based on the roundness ratio value, Soewarno (1991), divides it into two Watershed forms. If the Rc value> 0.5 then the Watershed is round, while if the Rc value <0.5 the Watershed is elongated (Table 3).

2.6.5 River Flow Patterns

River flows in all watershed flow according to a rule, namely that the river flow is connected by a network where branches and tributaries flow into a large main river and form a certain pattern. The pattern depens on the topography, climate and vegetation conditions in the watershed.

3. RESULT AND DISCUSSION

3.1 River Basin Delineation Analyst

Based on the analysis using the Spatial Hydrology Analysis tool, the watershed delineation results at the research site are shown in Figure 2. The watershed area obtained for each watershed is shown in Table 4.

(a) (b) (c)

Figure 2. The image of the watershed delineation results at the Research Location. (a) Krueng Bayeun Watershed, (b) Krueng Langsa Watershed, (c) Krueng Tamiang Watershed.

Table 4. Results of Morphometric Parameter Measurements at the Research Location

Watershed	Results of Morphometric Parameter Measurements		
	Length of Main River (km)	Area (km^2)	Around (km)
Krueng Bayeun	25,02	388,98	142,94
Krueng Langsa	32,92	220,57	93,53
Krueng Tamiang	145,31	4.537,59	407,84

Source: GIS Data Processing Results, 2024.

From the data in Table 4 above, it can be seen that the area of the Krueng Bayeun Watershed (38,892 ha) and Krueng Langsa Watershed (22,057 ha) is categorized as a small watershed (10,000 - <100,000 ha) based on the watershed classification from the Ministry of Forestry. Meanwhile, the Krueng Tamiang Watershed (453,759 ha) is categorized as a medium watershed (100,000 - <500,000 ha). Overall, although the Krueng Tamiang Watershed has a main river length that is not much different from the watersheds (DTA) of other watersheds, its area and circumference are much larger, indicating that this watershed covers a wider and more complex hydrological area. This has the potential to affect flow patterns, erosion rates, and water storage capacity compared to smaller watersheds.

3.2 Stream Network

The image of the results of the Stream Network or Watershed flow network at the Research Location can be seen in Figure 3. According to (Kevin, 2020), delineation of River Basin Watershed boundaries is the process of determining an area that contributes to flowing rainfall (input) into surface flow at one output point and the further downstream the river order will increase. Based on the results of the Watershed delineation analysis at the research location, it was found that the main boundary of the black line indicates the water catchment area that flows towards the main river, rainwater that falls into this area will flow into the river network before finally reaching the outlet point. The dark blue line (Moorea Blue) indicates the main river (primary) while the yellow line (Solar Yellow) indicates the tributaries (secondary) that flow into the main river and the dark green line (Fir Green) indicates the tributaries (tertiary) that flow into the secondary river. The black dot on the map indicates the outlet point in the Watershed area at the three research locations, all directions of water flow will lead to that point as the final destination because that point is the location where the flow empties.

A denser river network tends to accelerate surface flow, increasing the risk of flooding, while a sparser network allows water to infiltrate the ground and reduce the potential for flooding. In addition, geological characteristics also play an important role in river flow dynamics. Previous research by (Nurfaika, 2015) stated that the river channel in this area passes through rocks with medium resistance to erosion, so that the volume of sediment transport carried by the flow is relatively small. This condition can slow down river shallowing and also affect the river's capacity to drain water efficiently.

Figure 3. Stream Network Results at the Research Location Watershed

Figure 4. Slope Results at the Research Location Watershed

Table 5. Results of Morphometric Parameter Calculations of the Krueng Bayeun Watershed

No	Parameter	Calculation Results	
1	Many Orders	4	
2	Watershed Area	388,98km^2	
3	Around Watershed	142,94 km	
4	River Network	Number of Branches	Length (km)
	Orde 1	54	119,64
	Orde 2	25	47,81
	Orde 3	14	32,69
	Ordo 4	1	31,34
	Grand Total	94	231,48
5	Watershed slope		
	0-8%	151,30 km^2	
	8-15%	114,70 km^2	
	15-25%	76,15 km^2	
	25-45%	37,56 km^2	
	>45%	5,16 km^2	
	Grand Total	384,87 km2	
6	Watershed Form	Roundness ratio (Rc)= 0,23 (Elongated)	
7	Drainage Density	Dd= 0,59 (Currently)	
8	Flow Pattern	Dendritic	
9	Bifurcation Ratio (Rb)	WRb= 4,69	
10	River Order Frequency Ratio (F)	$F = \frac{Total\ Order\ Amount}{Watershed\ Area}$ $F = \frac{94}{388,97} = 0,24$	

3.3 Morphometric Characteristics of River Basins

3.3.1 Calculation of Area, Length of Main River, and Circumference of Watershed

The results of the calculation of the area of the watershed, the length of the main river, and the circumference of the watershed in the three watersheds at the Research Location can be seen in Table 5, Table 6, and Table 7.

Table 6. Results of Morphometric Parameter Calculations of the Krueng Langsa Watershed

No	Parameter	Calculation Results	
1	Many Orders	4	
2	Watershed Area	220,57 km²	
3	Watershed Around	95,53 km	
4	River Network	Number of Branches	Panjang (km)
	• Orde 1	43	53,62
	• Orde 2	31	27,27
	• Orde 3	1	32,92
	Grand Total	75	113,81
5	Watershed Slope		
	0-8%	126,15 km²	
	8-15%	43,82 km²	
	15-25%	29,53 km²	
	25-45%	16,81 km²	
	>45%	1,71 km²	
	Grand Total	218,02 km²	
6	Watershed Form	Roundness (Rc)= 0,30 (Elongated)	
7	Drainage Density	Dd= 0,99 (Currently)	
8	Flow Pattern	Dendritic	
9	Bifurcation Ratio (Rb)	WRb= 4,82	
10	River Order Frequency Ratio (F)	$F = \frac{Total\ Order\ Amount}{Watershed\ Area}$ $F = \frac{75}{220,573} = 0,34$	

Table 7. Results of Morphometric Parameter Calculations of the Krueng Tamiang Watershed

No	Parameter	Calculation Results	
1	Many Orders	6	
2	Watershed Area	4.537,59 km²	
3	Watershed Around	407,84 km	
4	River Network	Number of Branches	Length (km)
	• Orde 1	481	990,20
	• Orde 2	227	496,80
	• Orde 3	103	166,58
	• Orde 4	129	198,77
	• Orde 5	1	145,31
	Grand Total	941	1.997,66
5	Watershed Slope		
	0-8%	594,57 km²	
	8-15%	553,89 km²	
	15-25%	706,68 km²	
	25-45%	1.182,76 km²	
	>45%	1.487,89 km²	
	Grand Total	4.525,79 km²	
6	Watershed Form	Roundness ratio (Rc)= 0,34 (Elongated)	
7	Drainage Density	Dd= 0,47 (Currently)	
8	Flow Pattern	Dendritic	
9	Bifurcation Ratio (Rb)	WRb= 8,90	

10	River Order Frequency Ratio (F)	$F = \frac{Total\ Order\ Amount}{Watershed\ Area}$ $F = \frac{941}{4.537,59} = 0,20$

Source: Results of GIS Data Processing Calculations for 2024.

Krueng Langsa has the largest percentage in the flat class (0-8%) of 57.9%, the sloping class (8-15%) of 20.1% and the rather steep class (15-25%) of 13.54%. While the steep class (>25%) and very steep (>45%) are only around 7.70% and 0.8% respectively. This shows that most of the watershed area is relatively flat, so the potential for erosion is relatively low, but there are still areas with moderate to very steep slopes that have the potential to increase the risk of erosion, Krueng Bayeun shows similar results, with the largest percentage in the flat class (39.30%) and sloping (29.80%), and the rather steep class (19.8%). The steep and very steep classes are only 9.76% and 1.34% respectively, this shows that this area is also dominated by low to moderate slopes. Krueng Tamiang has different slopes, with the highest percentage in the very steep class (>45%) at 32.9%, steep class (25-45%) at 26.13% and rather steep class (15-25%) at 15.61%.

This area shows a higher level of slope, thus potentially increasing the risk of erosion and rapid surface flow. This is in accordance with previous research, According to Lesmana *et al*., 2021 explained that a steep slope will increase the gravitational force and scouring energy, thereby increasing the potential for erosion and sedimentation. So that slope classification is very important in water resource management and soil conservation because it is directly related to flow speed and erosion potential in the watershed area.

Based on the data on the Roundness Ratio (Rc) values in the three Watersheds of Krueng Bayeun, Krueng Langsa, and Krueng Tamiang watersheds, it shows that all three have elongated watershed shapes with Rc values of 0.23; 0.30; and 0.34 respectively, all of which are below the threshold value of 0.50. According to Soewarno (1991) classifying watershed shapes based on Rc values, with Rc values ≤ 0.5 indicating elongated shapes associated with slow hydrological responses and lower flood risks. Previous research by [3] also emphasized that watersheds with elongated shapes have characteristics of peak discharges that arrive and fall more slowly than rounded watersheds. Thus, the Rc values indicating elongated shapes in the three watersheds provide an important picture of flow patterns and lower potential flood risks.

Based on the river order values in tables 5, 6 and 7, the higher the river order value, the greater the role of the river in channeling the main flow downstream, so that the existence of high-order rivers in the Krueng Tamiang Watershed indicates a mature and well-structured drainage network. This is in line with (Nurfaika, 2015) who stated that the river order value will continue to increase if the same river order meets. In addition, (Prabowo, 2018) added that the dominance of low-order rivers indicates the number of tributaries that play a role in collecting water upstream, while high-order rivers act as the main channels for water flow downstream. Most of the Rb values in the research area have values between 3-5 which indicate homogeneous geological conditions except for the Krueng Langsa watershed with a value of 2-2.5. According to (Purboyo, 2024) if the Rb value is <3 or >5 then the area is not normal and there is a possibility of tectonic control, indicating that the Watershed is slightly tectonically deformed but this structure does not change its drainage pattern.

The results of the flow direction analysis in the Krueng Langsa, Krueng Bayeun and Krueng Tamiang watersheds show the same flow pattern, namely the dendritic pattern. The pattern is characterized by water flow starting from the upstream area with high elevation, moving down the slope through the river network and ending at the outlet point in the downstream area. The dendritic pattern resembles tree branches and is generally formed in areas with relatively homogeneous topography and geological structures that do not experience many faults.

The novelty of this study lies in its ability to show that the relatively elongated shape of the watersheds in the three study areas does not automatically result in low flood risk. Local topography and flow network structure have been shown to play a greater role in determining flow response. Thus, this study provides a new perspective that morphometric analysis needs to be combined with topographic analysis to obtain a more accurate of flood vulnerability.

In practical terms, the results of this study can form the basis for more location specific watershed management, where flood mitigation strategies cannot be generalized across watersheds even within the same regional area. This approach makes an important contribution compared to previous studies, which tended to provide general recommendations for watershed management without considering the internal characteristic of each watershed.

4. CONCLUSIONS

Based on the results of the River Basin (DAS) delineation analysis at three research locations, the boundaries of the Krueng Bayeun (scale 1:125,000), Krueng Langsa (scale 1:90,000), and Krueng Tamiang (scale 1:425,000) watersheds were successfully determined, with the watershed area clearly depicted in the form of blue polygons as the main river catchment areas. The results of this analysis can be used as a basis for planning water resource management, conservation, and mitigation of floods and droughts. Spatial Analyst Hydrology analysis using Digital Elevation Model (DEM) data shows that the Krueng Bayeun, Krueng Langsa, and Krueng Tamiang watersheds have roundness ratio values of 0.23, 0.30, and 0.34, respectively, indicating that all three are elongated, with the direction of water flow concentrated towards low areas, thus potentially experiencing water accumulation and increasing the risk of flooding, especially during the rainy season. In addition, all three watersheds are dominated by dendritic flow patterns with moderate river density, indicating sufficient water reserves. In terms of slope gradient, the Krueng Bayeun and Krueng Langsa watersheds are dominated by flat to gentle slopes, which cause slower river flow, resulting in pools of water that tend to persist longer around the river. Meanwhile, the Krueng Tamiang watershed is dominated by steep to very steep slopes, which cause faster river flow, increase erosion rates, and potentially trigger flooding in downstream areas.

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